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Observations of the natural ventilation of buildings

1. The relative importance of wind and stack pressures

The theoretical head due to wind pressure (the velocity head) has been shown as

$$H = .00051\ v^2 \text{ ins. w.g.}$$

where v is the wind speed in m.p.h.

The head due to stack pressure has been shown as

$$H = 12.\rho \frac{\Delta T}{460 + T} .h \text{ ins. w.g.}$$

where T is the external temperature in degrees F.

ΔT is the temperature difference inside and outside the building.

h is the vertical separation of inlet and outlet in feet.

ρ is the outside air density.

If reasonable values are given to the variables in the expression for stack pressure e.g., $\Delta T = 20°F$, $T = 50°F$, $h = 10ft$, it is seen that the head due to wind pressure will exceed that due to stack pressure when $v \simeq 3.5$ m.p.h.

If the exposure of farm buildings is such that a mean wind speed greater than 3 to 5 m.p.h. can be assumed, then the dominant factor in their natural ventilation is likely to be wind rather than stack pressure.

2. Pressures on obstacles in a fluid stream

In most practical cases, only a fraction of the airstream approaching an obstacle is actually brought to rest at the windward face, the greater proportion of the flow being deflected around or over the obstacle. Consequently only a portion of the windward face experiences the full impact pressure. Further, except in the case of a perfectly streamlined body, a suction pressure (i.e. a deficit below the prevailing static pressure) will develop on the rear faces of the obstacle.

Wind tunnel experiments have shown that for rectangular plates and prisms (of finite downwind dimensions) placed on a horizontal surface the ratio:-

$$\frac{\text{Excess pressure averaged over the windward face}}{\text{Impact pressure}}$$

varies between 0.5 and 0.7 depending partly on the roughness of the upwind surface. The leeward suction averages around 0.3 to 0.4 of the impact pressure. Thus the total pressure drop from front to back of the plate or prism is of the same order as the velocity head.

3. Observations of wind pressures on houses and walls

(i) Houses.

Much of the reported field work in this subject has come from the Building Research Station, Garston.

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Direct measurements of wind pressure have been made together with simultaneous measurements of wind speed and direction and the ventilation rates of individual rooms (and so of entire houses).

For normal incidence, the ratio of the observed wind pressure to the velocity head was found to be 0.86 and in general, the head due to wind pressure was found to be

$$H = .00044\ v^2 \cos^2 \theta \quad \text{ins. w.g.}$$

where v, the wind velocity is measured in m.p.h. and θ is the angle of incidence of the wind, measured from the normal to the front of the house.

If H varies as $\cos^2 \theta$, this implies a ventilation rate V, varying as $\cos \theta$.

(ii) Walls.

For normal incidence, the head due to wind pressure across individual walls was found to be

$$H = .00041\ v^2 \quad \text{ins. w.g.}$$

and we see that for winds normal to the front of the house, almost all the pressure drop occurred, on the wind-ward wall.

The reason for this unequal division of pressure drop is seen if one compares the size of the effective resistances in the air circuit. If the resistance to airflow through the wind-ward wall is R, and the resistance of outlets in each of the remaining three walls and a chimney is R, the effective resistance of the combined outlets is given by R/16, since the resistances are in parallel.

(iii) Comparison with wind tunnel experiments.

The field measurements of the total pressure drop across slightly permeable houses and walls are in good agreement with the wind tunnel measurements on solid models experiencing flow at normal incidence. Typical pressure patterns are shown in figure 1.

Wind tunnel experiments suggest that roof pressures are generally negative, except on the wind-ward side of a roof with a pitch greater than 35°. The pressures experienced at openings in a simple pitched roof are not entirely independent of its dimensions. There is a tendency, particularly with low pitched roofs, for the wind to eddy down and to give positive pressures away from the wind-ward edge. In such a case, air extracted at openings near the wind-ward edge could be returned through vents near the leeward edge.

4. Observations of the ventilation rates of rooms and buildings

(i) Rooms

As we have seen, the magnitude and sense of the flow of air through individual components of a ventilation system is related to the pressures and resistances found elsewhere in the circuit. The ventilation of a room cannot be examined theoretically without reference to the complex constituted by the remainder of the building and the prediction of a ventilation rate is thus difficult.

/ It was

It was found that the ventilation rate of a room could in general be expressed by an equation of the form

$$V = A_1 + B_1 v$$

where A_1 B_1 are constants

v is the external wind speed.

Correlations between V and v ranged from .57 to .91.

The uneven pressure drop across the walls of a house has been commented on, and the result is a greater movement of air through rooms on the windward side.

A relation between V and wind speed and direction of the form

$$V = A_2 + B_2 v + C_2 v \cos\theta + D_2 v \sin\theta$$

where A_2 B_2 C_2 D_2 are constants,

gave correlation coefficients between observed and predicted values of V which ranged from .75 to .95.

(ii) Buildings.

The exchange of air in a room is only in part direct to the outside, and the effect of wind direction on the total ventilation rate of a house was found to be small. The ventilation rate of a house was adequately given by an expression of the form

$$V = A_3 + B_3 v$$

In the experiments, ΔT, the difference between internal and external temperatures was fairly constant. The constant A_3 in the above expression may be regarded as including the ventilation due to stack pressure which becomes more pronounced at low wind speeds. The complete expression can be regarded as combining the two special cases of wind and stack pressure acting separately.

When wind and stack pressures act simultaneously, the resultant air flow should strictly be estimated by combining the effects of each pressure regime. As a compromise in practice, it is usual to calculate the air flow attributable to each pressure acting separately and to take the larger estimate as the effective ventilation rate. The procedure is justified in part by the fact that the pattern of air flow within the building is dependent both upon the motive force and the location of the vents. Quite generally when the motive force is wind pressure, air will enter through openings on the wind ward-walls and leave through the leeward walls. When stack pressure is the motive force, air will enter through openings in any wall at low level and leave through openings in any wall at high level. When wind and stack pressures act simultaneously the alignment of inlets and outlets is likely to be be different to when they act alone.

(iii) The effects of infiltration

The volume of air entering through fortuitous cracks around doors and windows etc., cannot in general be neglected. Equivalent areas for such cracks are shown in Table 1. The effect of weather stripping

/ external doors

external doors in the houses under investigation was to reduce the ventilation rate from around 2.8 air changes/hour to 2.0 changes/hour, when the mean wind speed was ~ 8.5 m.p.h.

Table 1. Typical Equivalent Areas

Component	Equivalent Area (sq. ins.).
Windows	
Unweather Stripped	13
Weather Stripped	3
Frame	1
Doors	
Unweather Stripped	13
Weather Stripped	7
Walls	
Unplastered	3
Plastered	0

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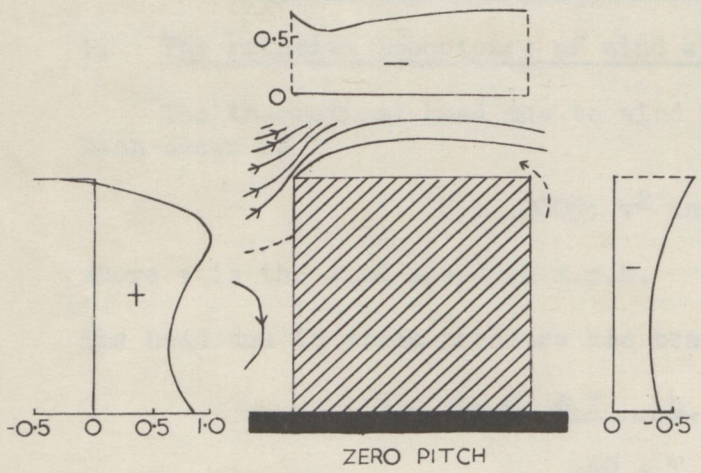
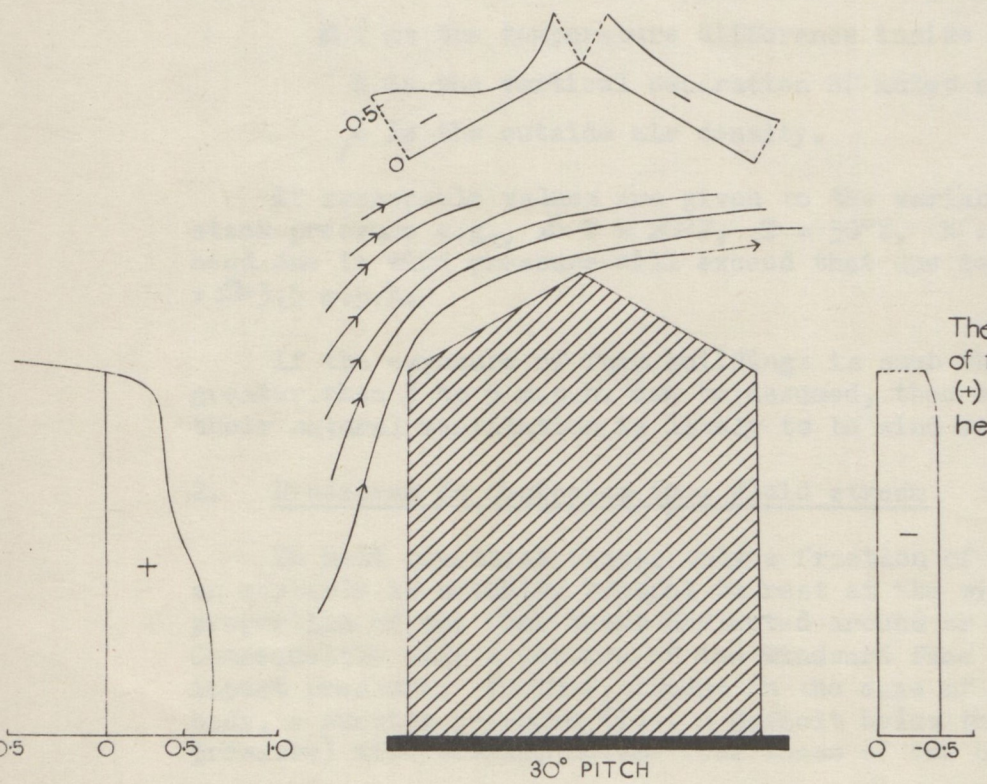
FIGURE 1

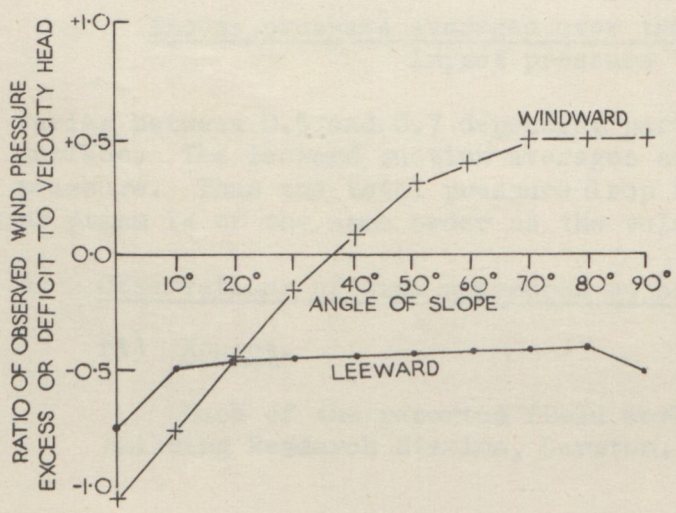


The pressure produced by a wind blowing normal to a model "building" (after Irminger and Nokkentved).



The perameter plotted is the ratio of the observed pressure excess (+) or deficit (-), to the velocity head.

FIGURE 2



Wind pressure on roof slopes.